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Balcerak et al.

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(54) **MODULAR LIQUID COOLING SYSTEM**

(75) Inventors: **John A. Balcerak**, Muskego, WI (US); **Jeremy J. Keegan**, Kewaskum, WI (US); **William K. Siebert**, West Bend, WI (US); **Neil Gollhardt**, Fox Point, WI (US); **Scott D. Day**, Richfield, WI (US)

(73) Assignee: **ROCKWELL AUTOMATION TECHNOLOGIES, INC.**, Mayfield Height, OH (US)

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This patent is subject to a terminal disclaimer.

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Related U.S. Application Data

(63) Continuation of application No. 11/854,818, filed on Sep. 13, 2007, now Pat. No. 8,081,462.

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H05K 7/20 (2006.01)
H01F 27/10 (2006.01)
H01L 23/473 (2006.01)
H01F 27/32 (2006.01)

(52) **U.S. Cl.**

CPC ***H01F 27/10*** (2013.01); *H01F 27/322* (2013.01); *H01F 27/325* (2013.01)

(58) **Field of Classification Search**

CPC H05K 7/20218–7/20381; H01I 23/473
USPC 361/679.46–679.54, 688–723, 676, 361/618, 620, 677; 165/80.4–80.5, 104.33, 165/185; 174/15.1–15.3, 16.1–16.3, 174/547–548; 257/712–722, E23.088; 336/55, 57, 60, 192, 198, 208

See application file for complete search history.

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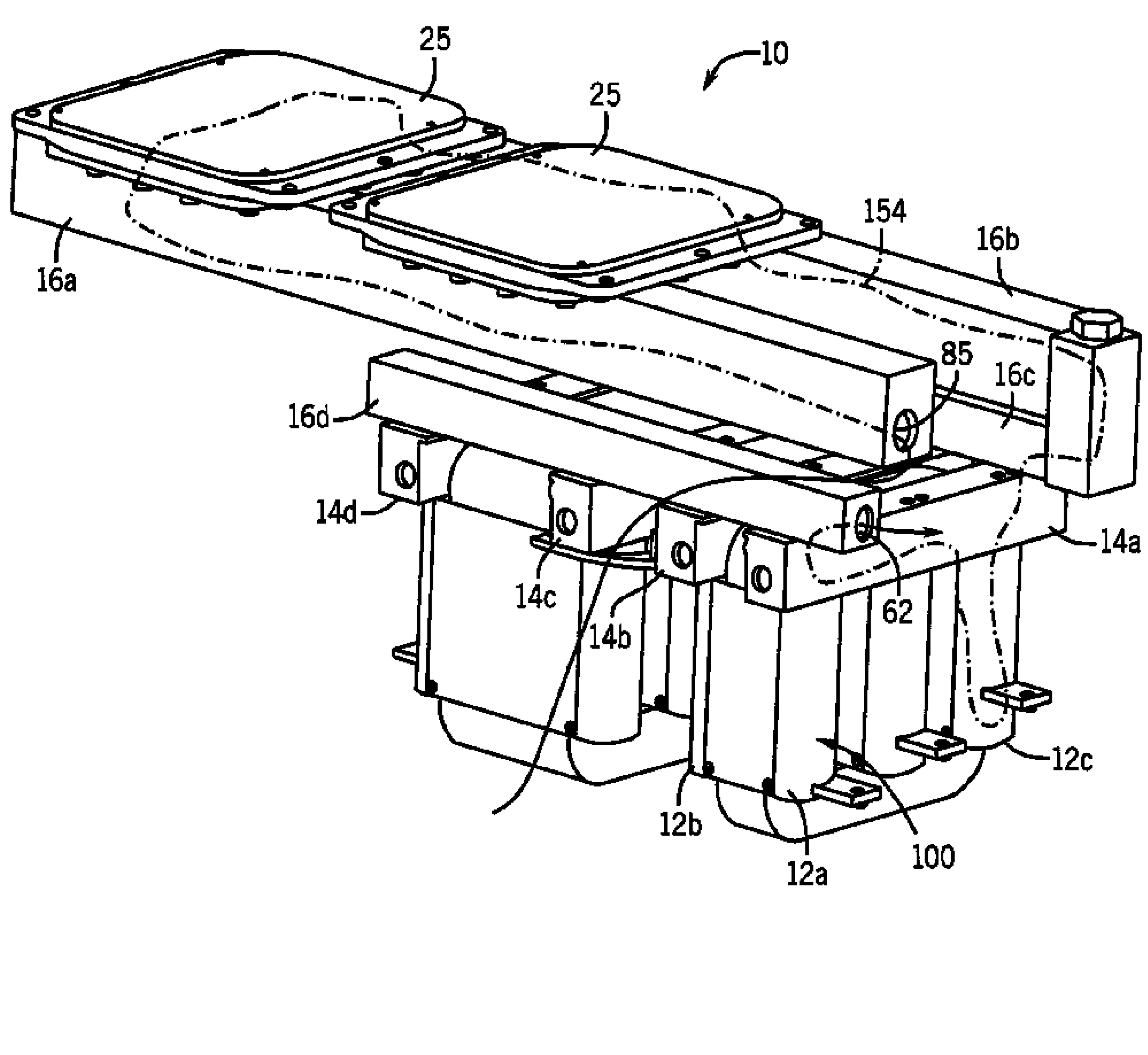
Primary Examiner — Anthony Haughton
Assistant Examiner — Razmeen Gafur
(74) *Attorney, Agent, or Firm* — Quarles & Brady LLP

(57) **ABSTRACT**

Cooling systems include a first passageway forming member that includes first and second ends and at least one connecting recess that opens into first and second passageways formed by the first passageway forming member. A second passageway forming member includes first and second ends and inlet and outlet ports proximate the first end such that the first end, including an elastomeric seal and the inlet and outlet ports, is sealably insertable in and removable from the at least one connecting recess, where the inlet port opens into the first passageway and the outlet port opens into the second passageway, and where, when the first end is inserted in the at least one connecting recess, the elastomeric seal is sandwiched between and in substantial contact with both the first end and the first passageway forming member.

19 Claims, 13 Drawing Sheets



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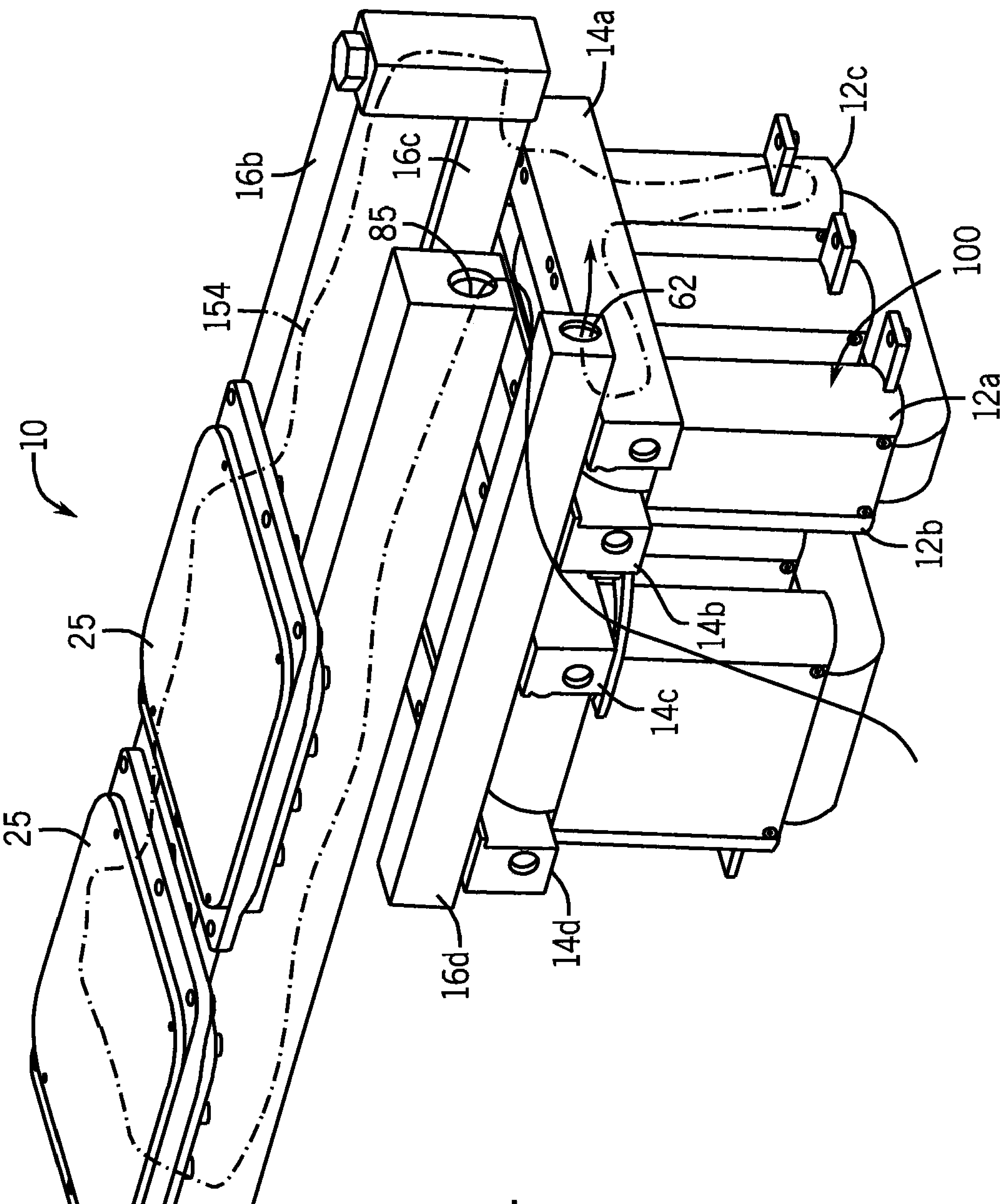

FIG. 1

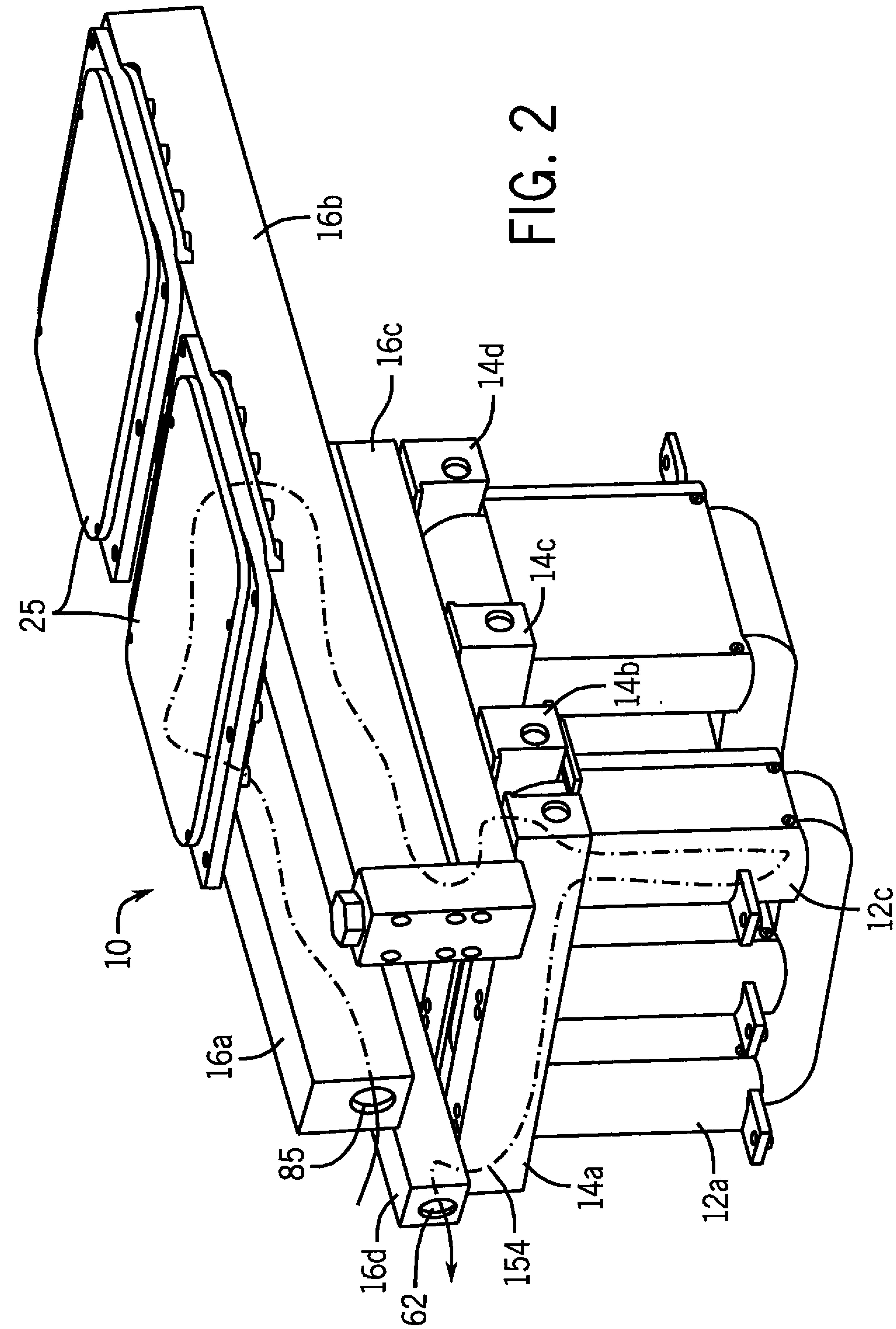

FIG. 2

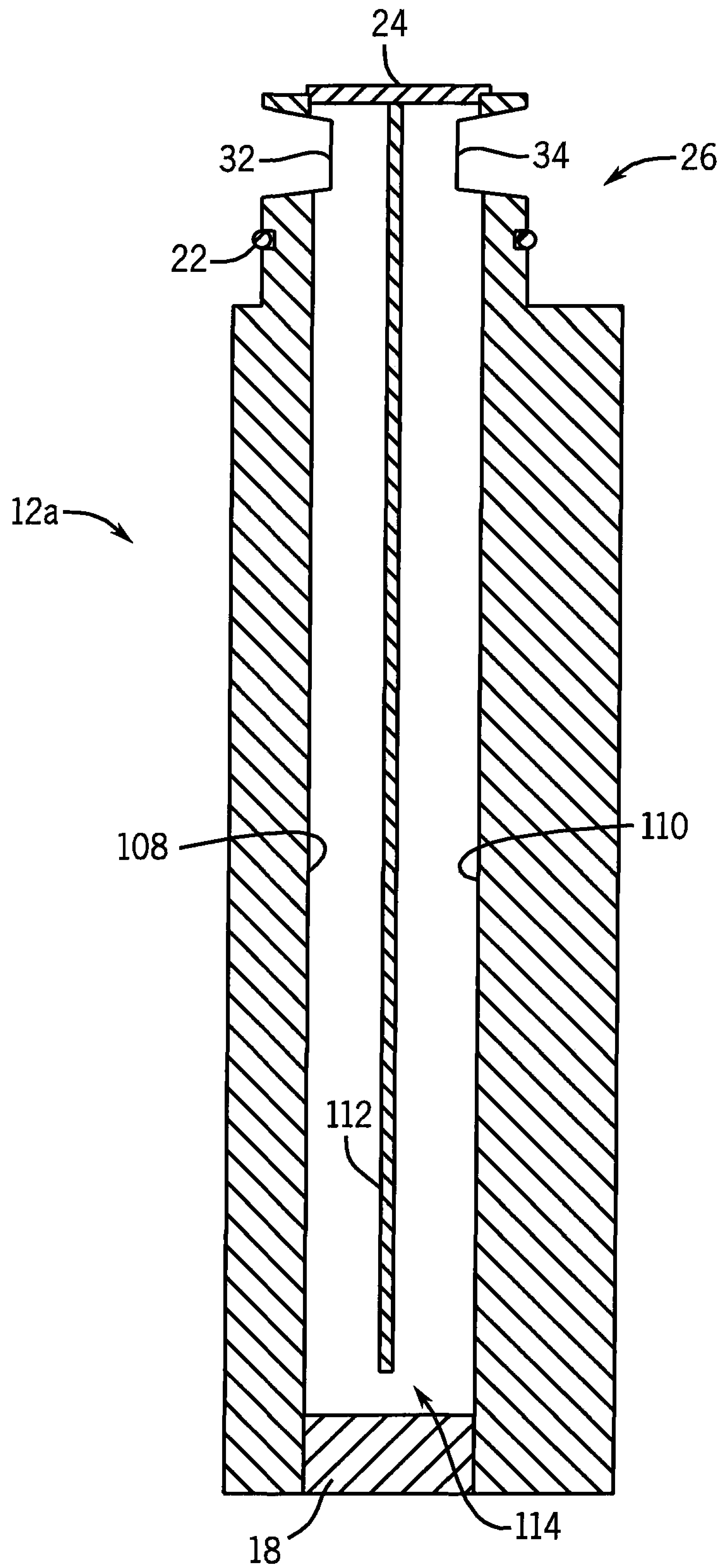

FIG. 3

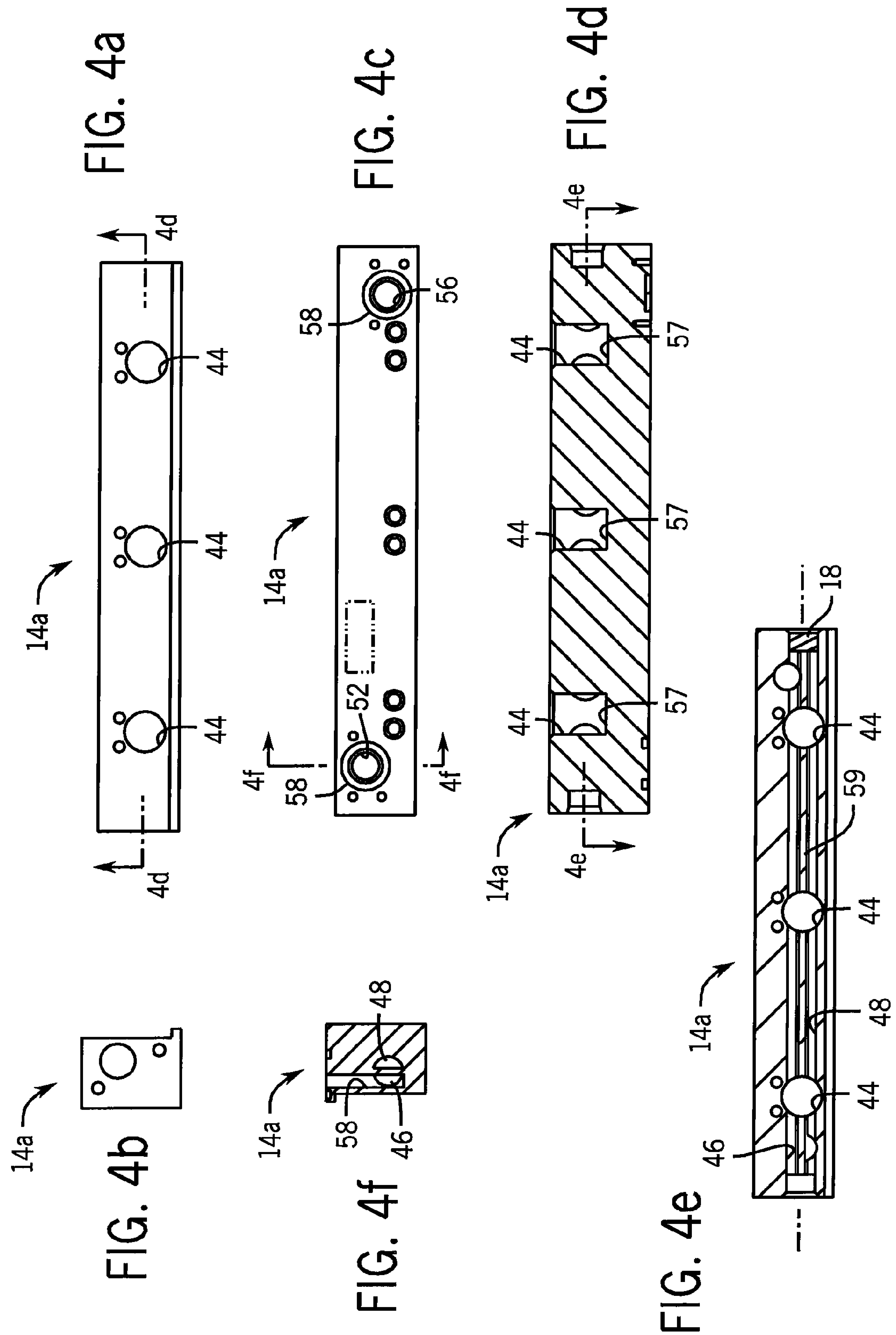

FIG. 4a

FIG. 4b

FIG. 4c

FIG. 4d

FIG. 4e

FIG. 4f

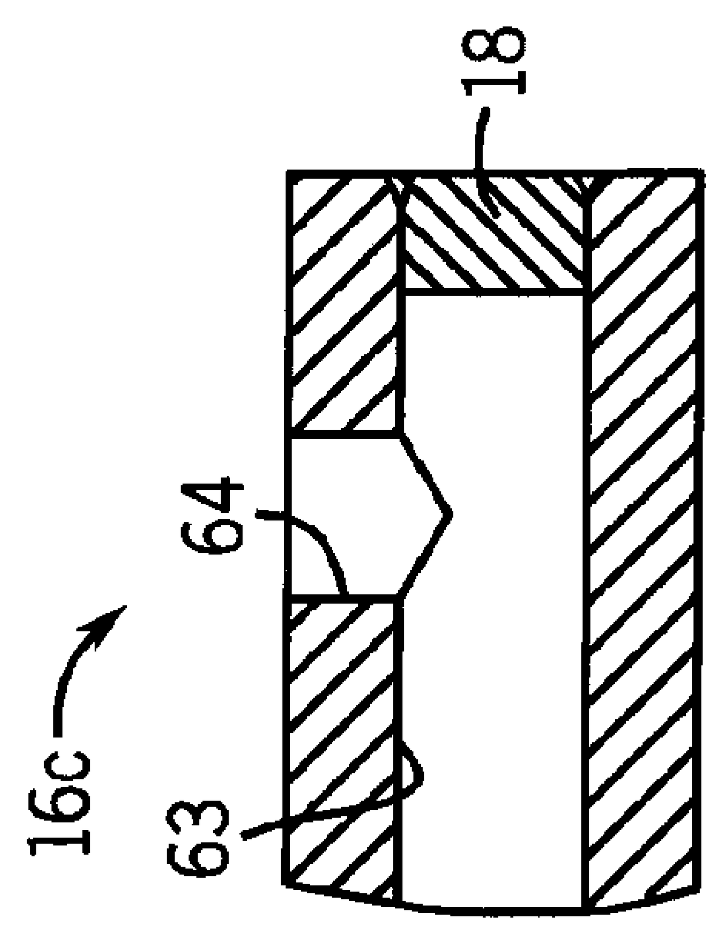

FIG. 5e

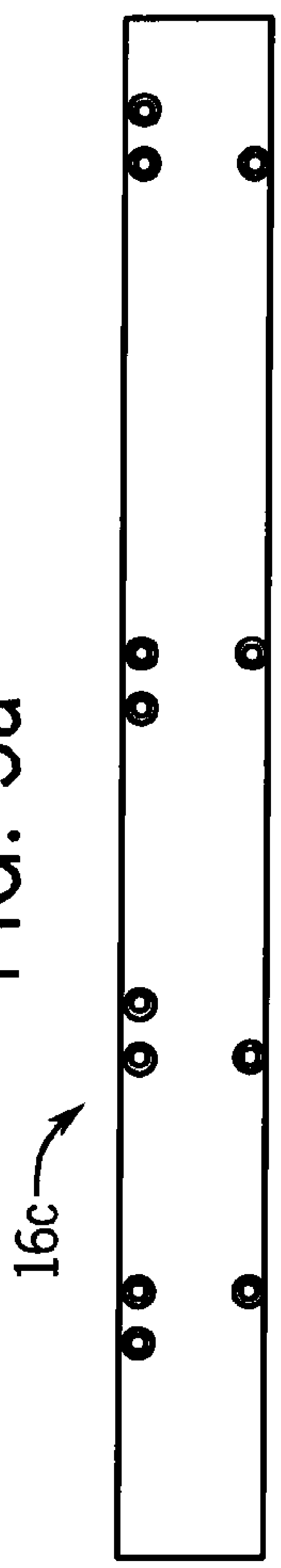

FIG. 5a

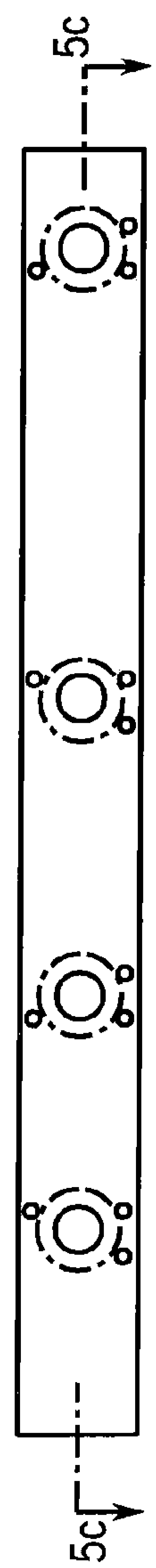

FIG. 5b

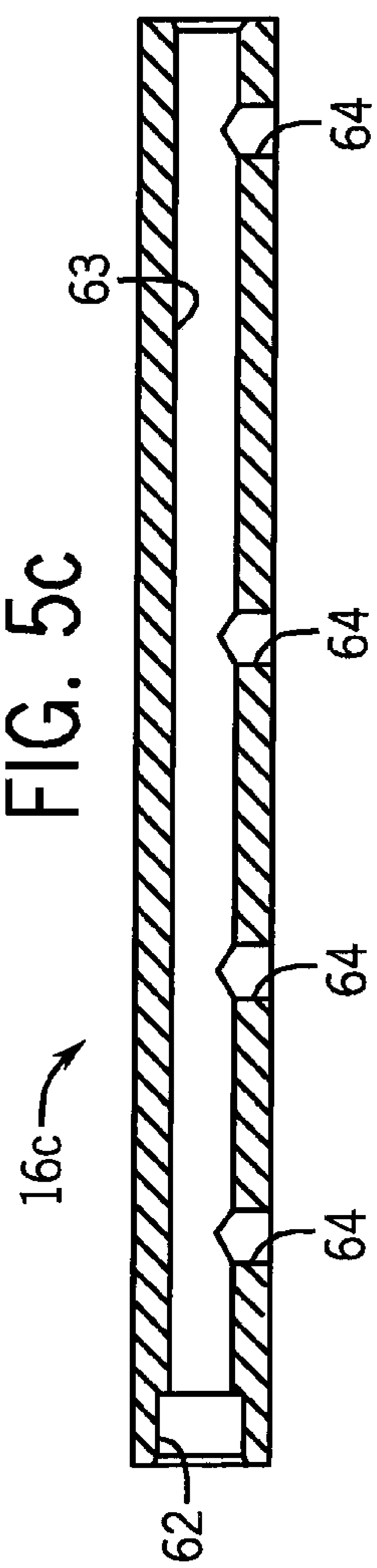

FIG. 5c

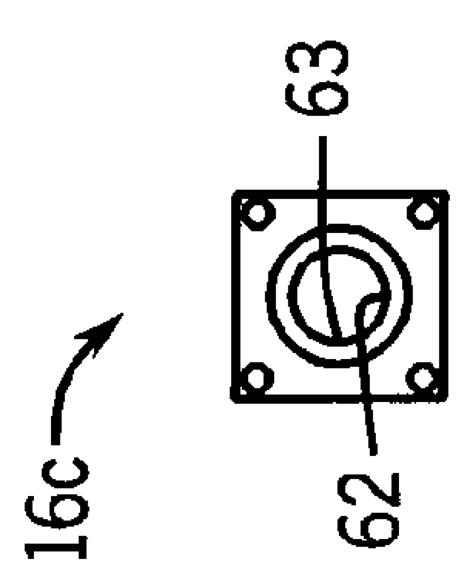

FIG. 5d

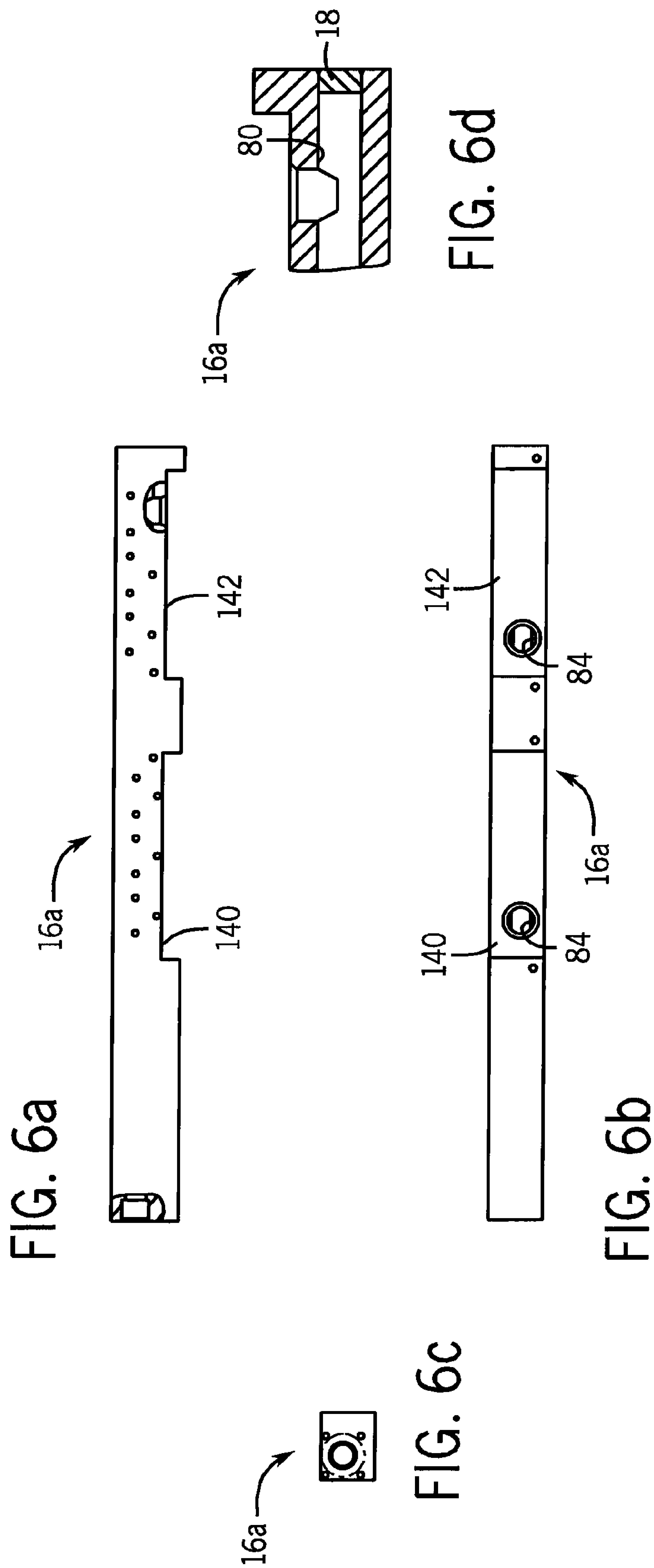

FIG. 6d

FIG. 6a

FIG. 6b

FIG. 6c

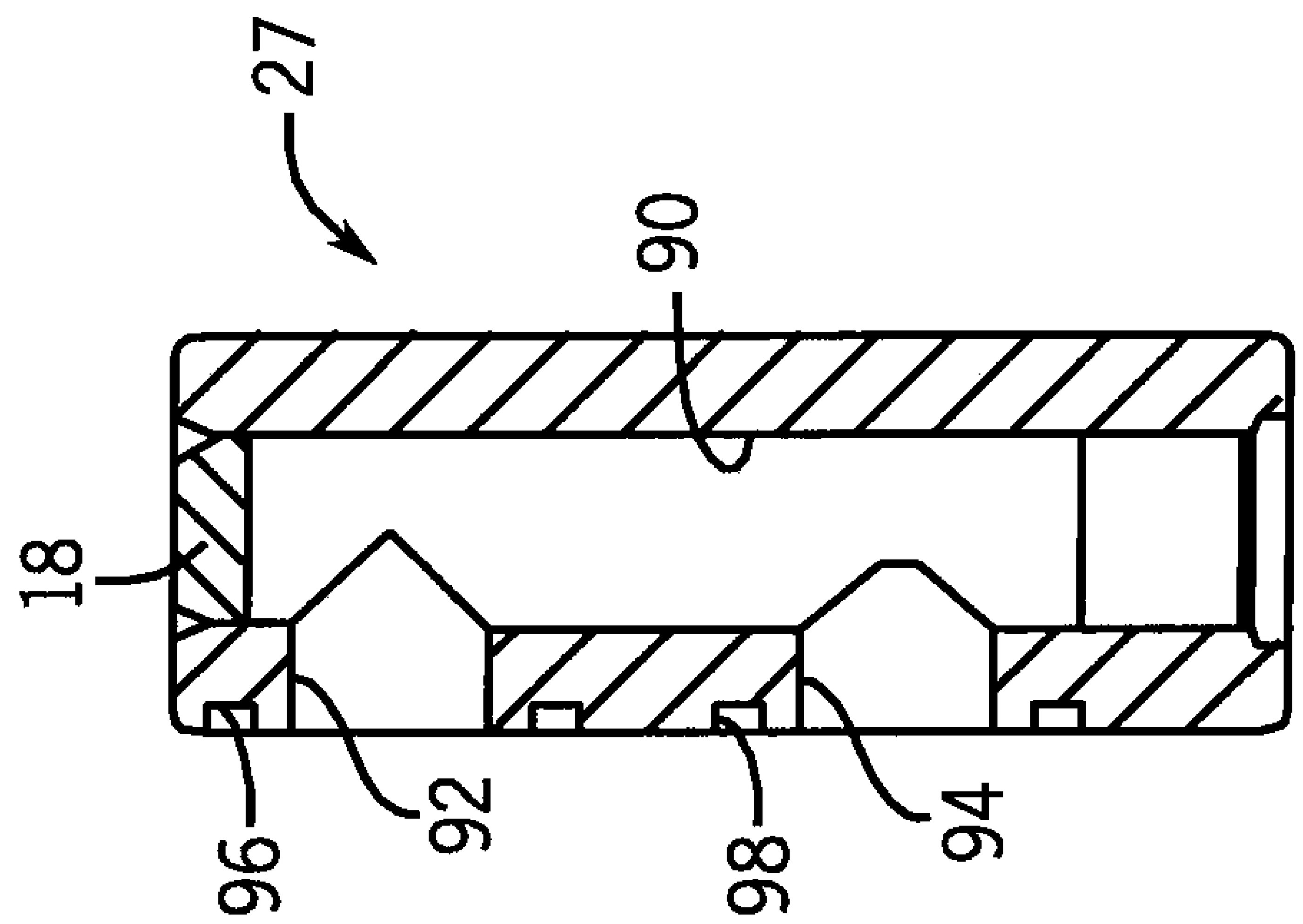

FIG. 7c

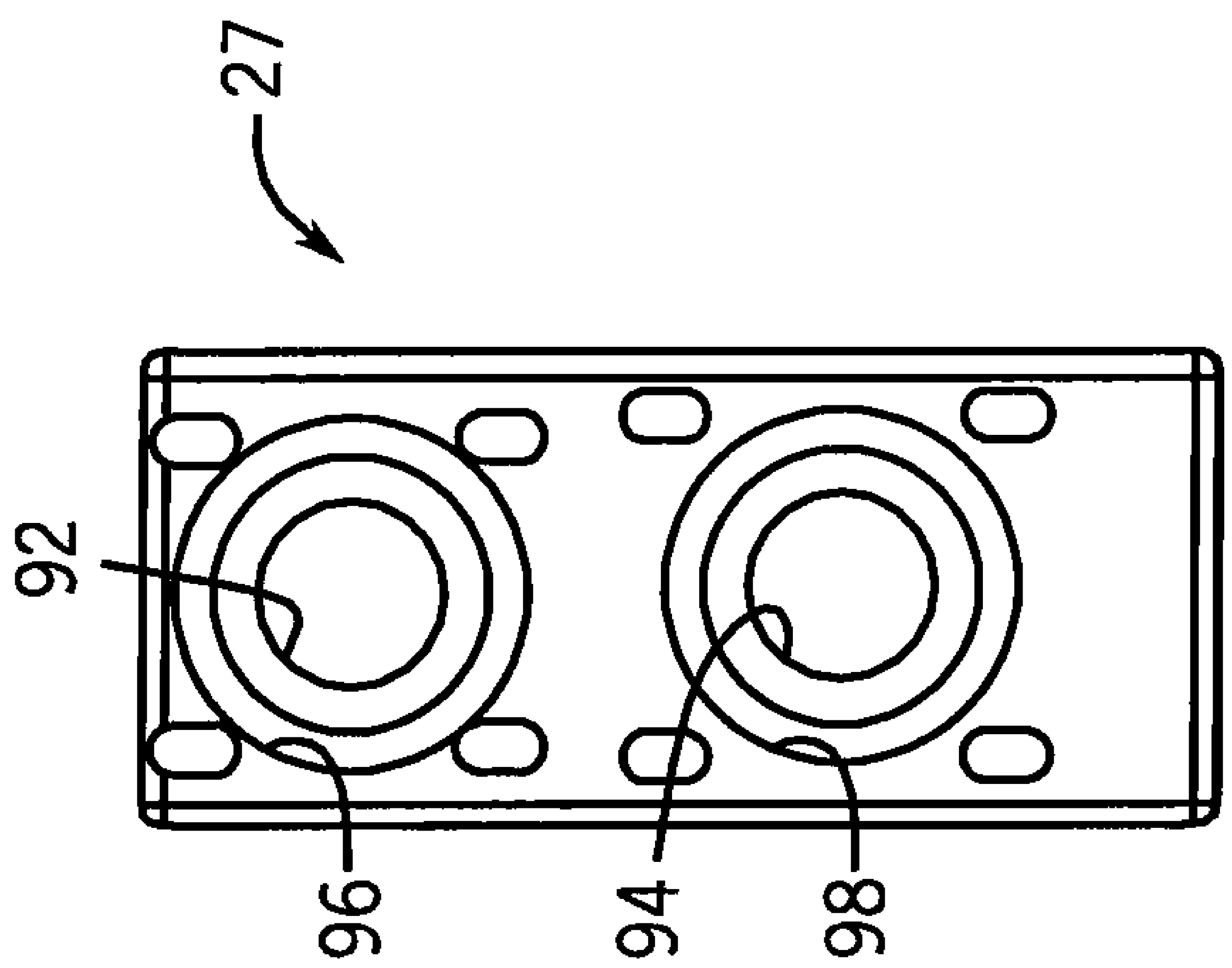

FIG. 7b

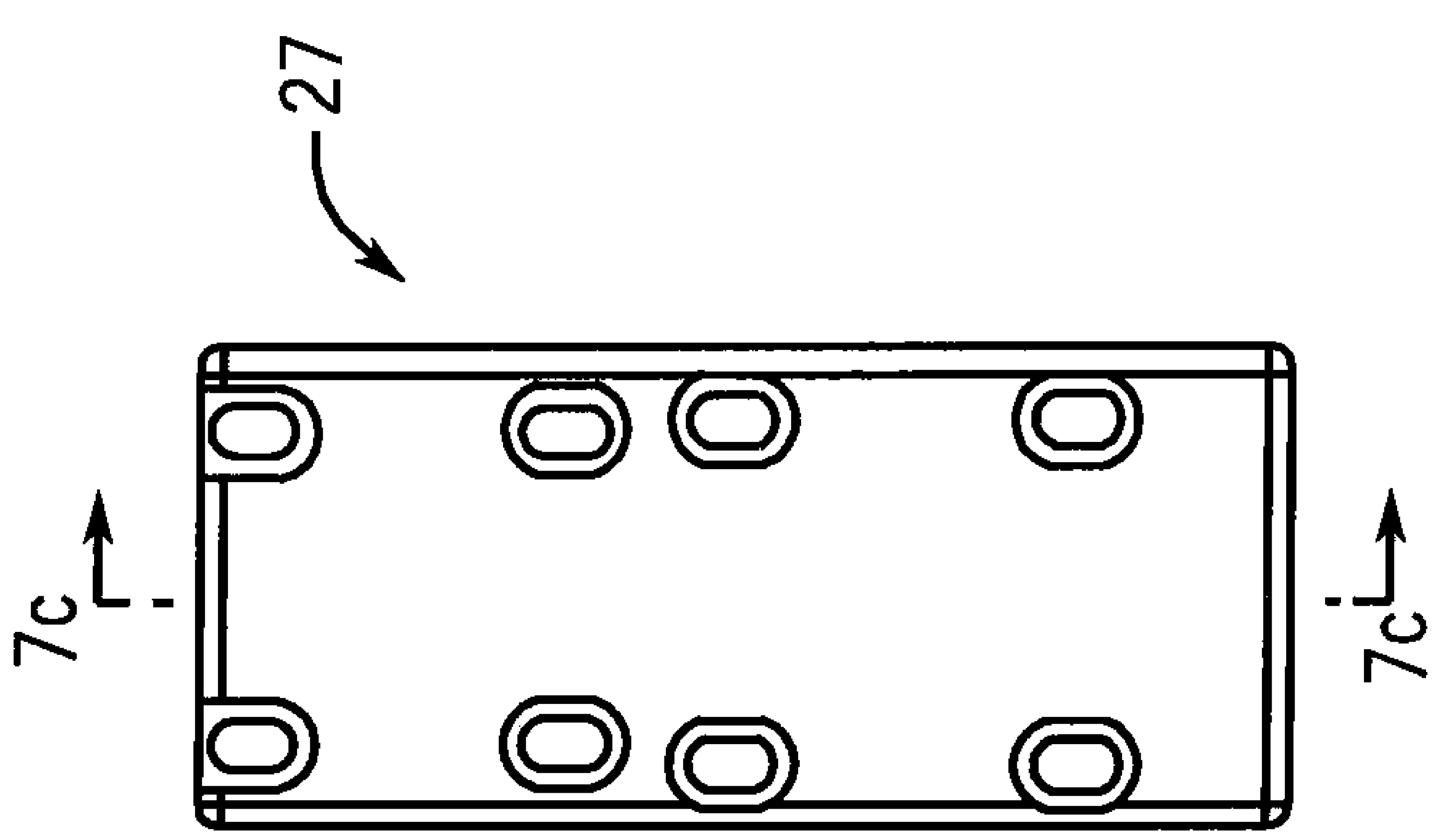

FIG. 7a

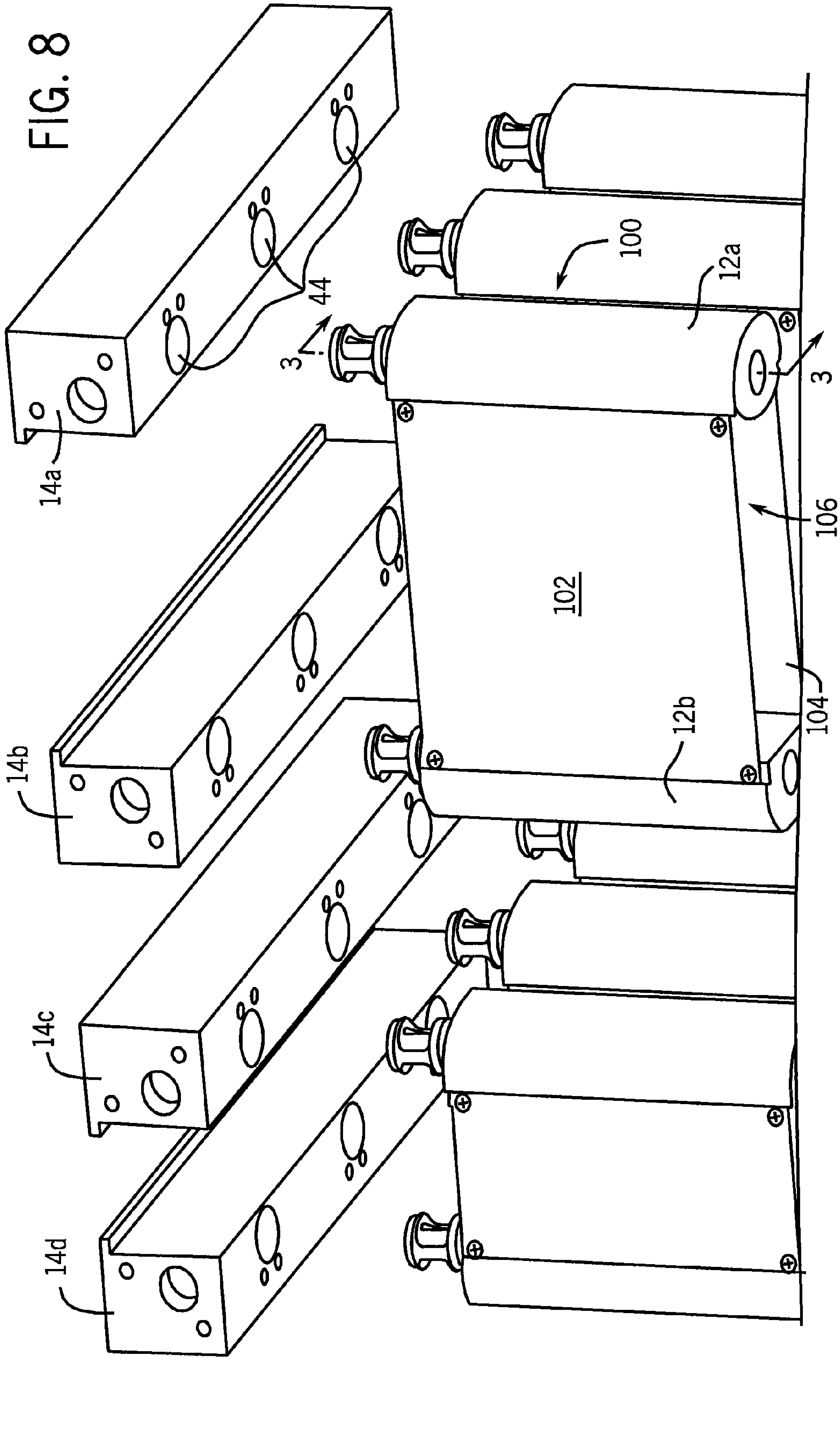

FIG. 8

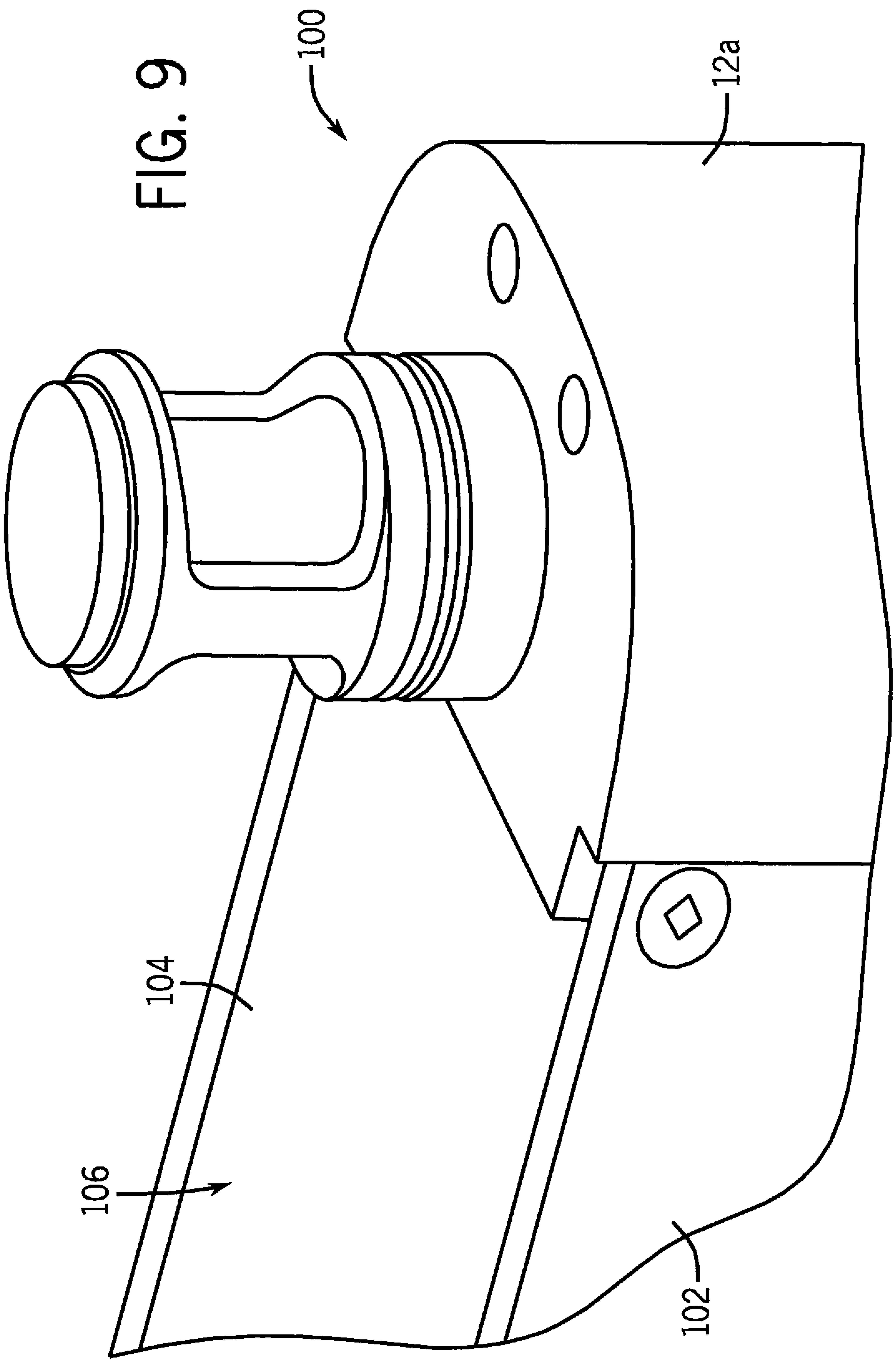

FIG. 9

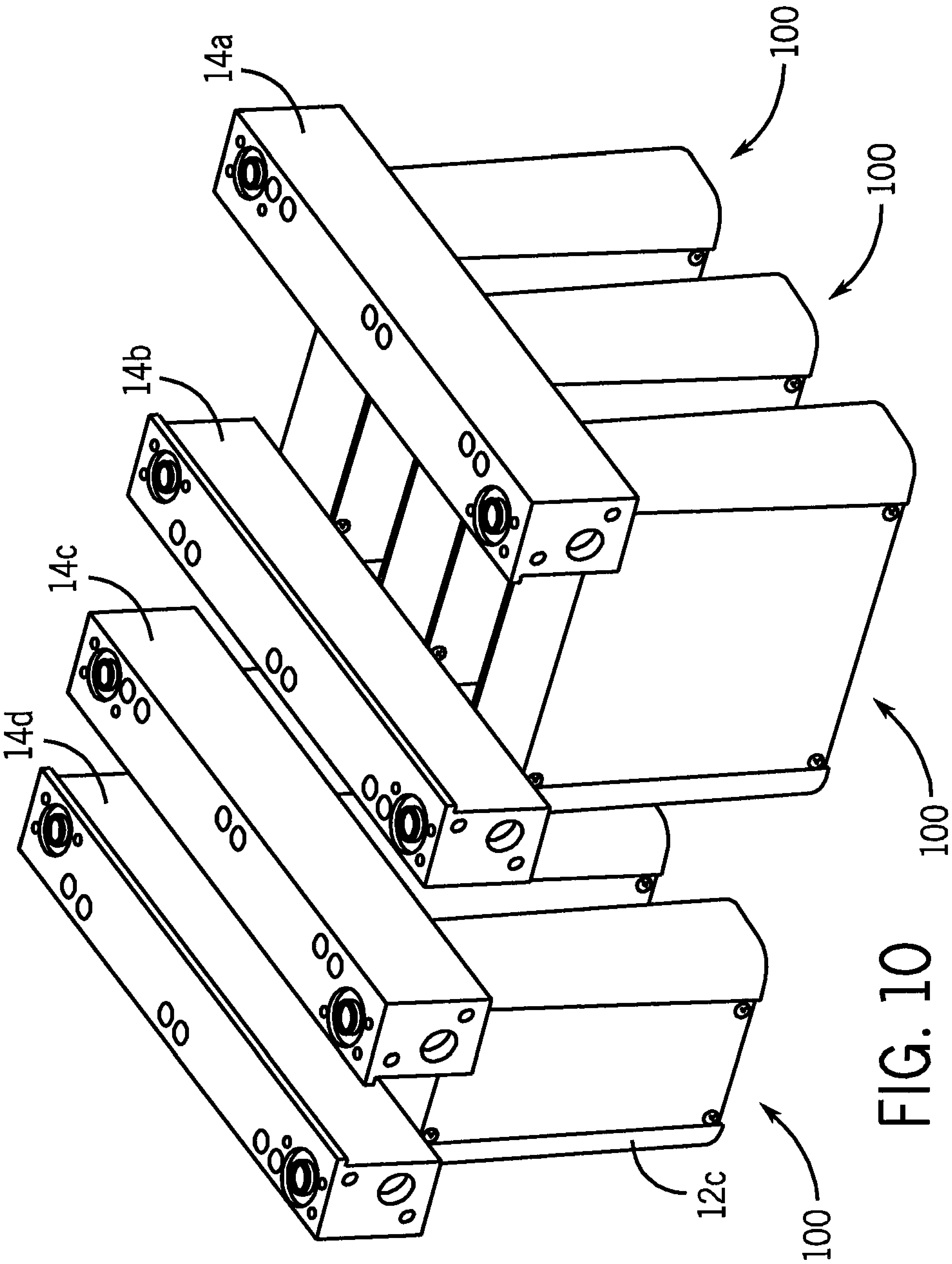

FIG. 10

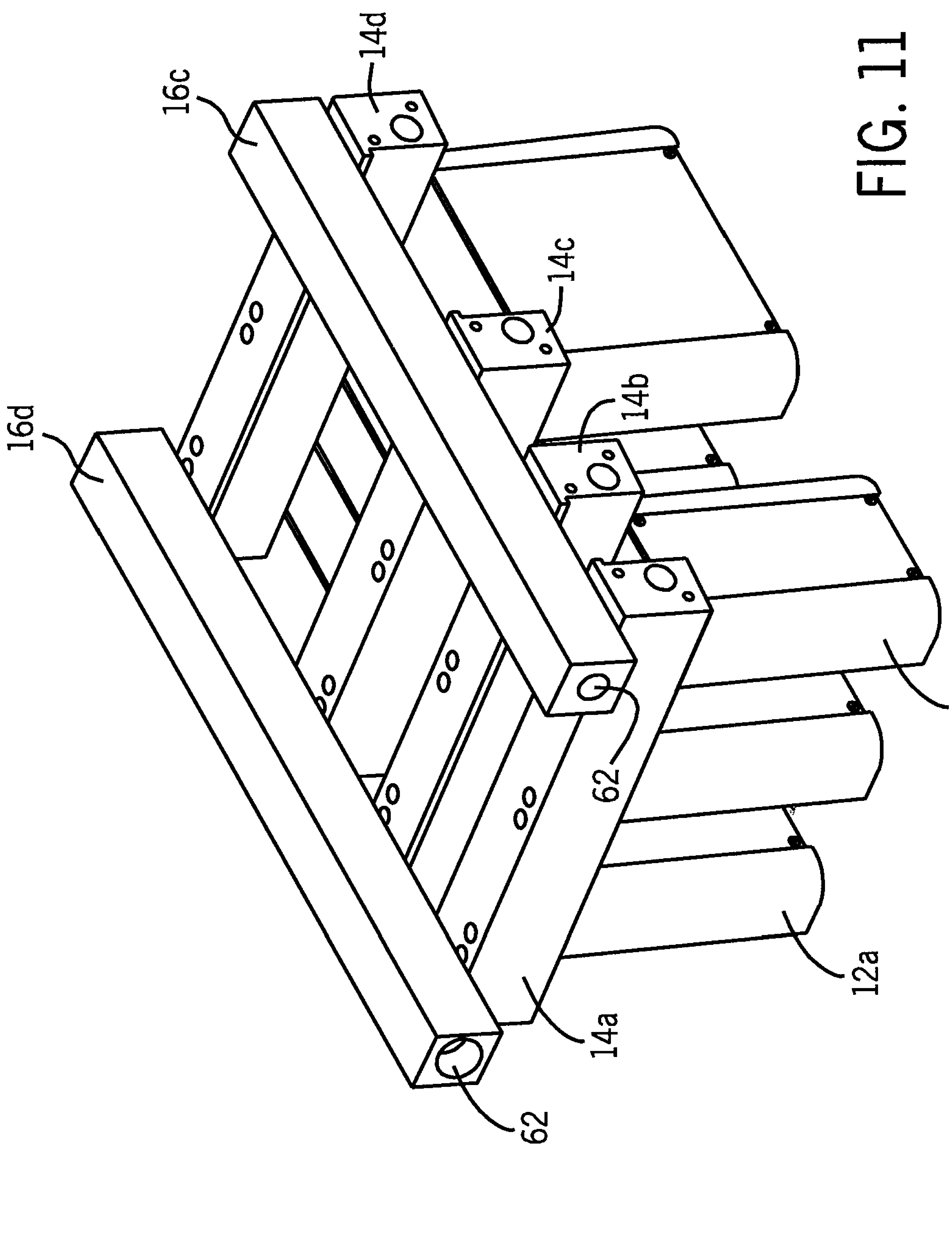

FIG. 11

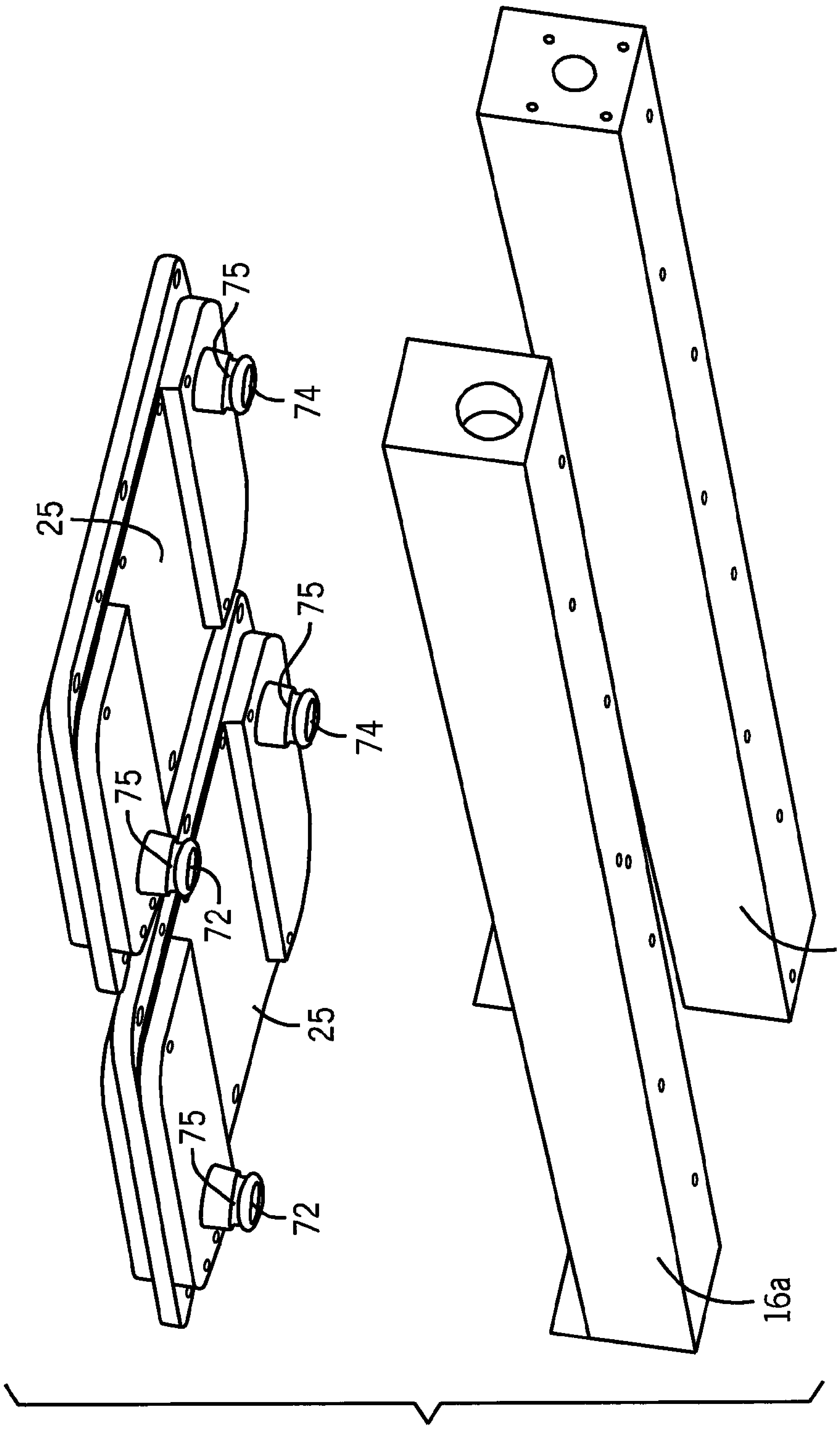

FIG. 12

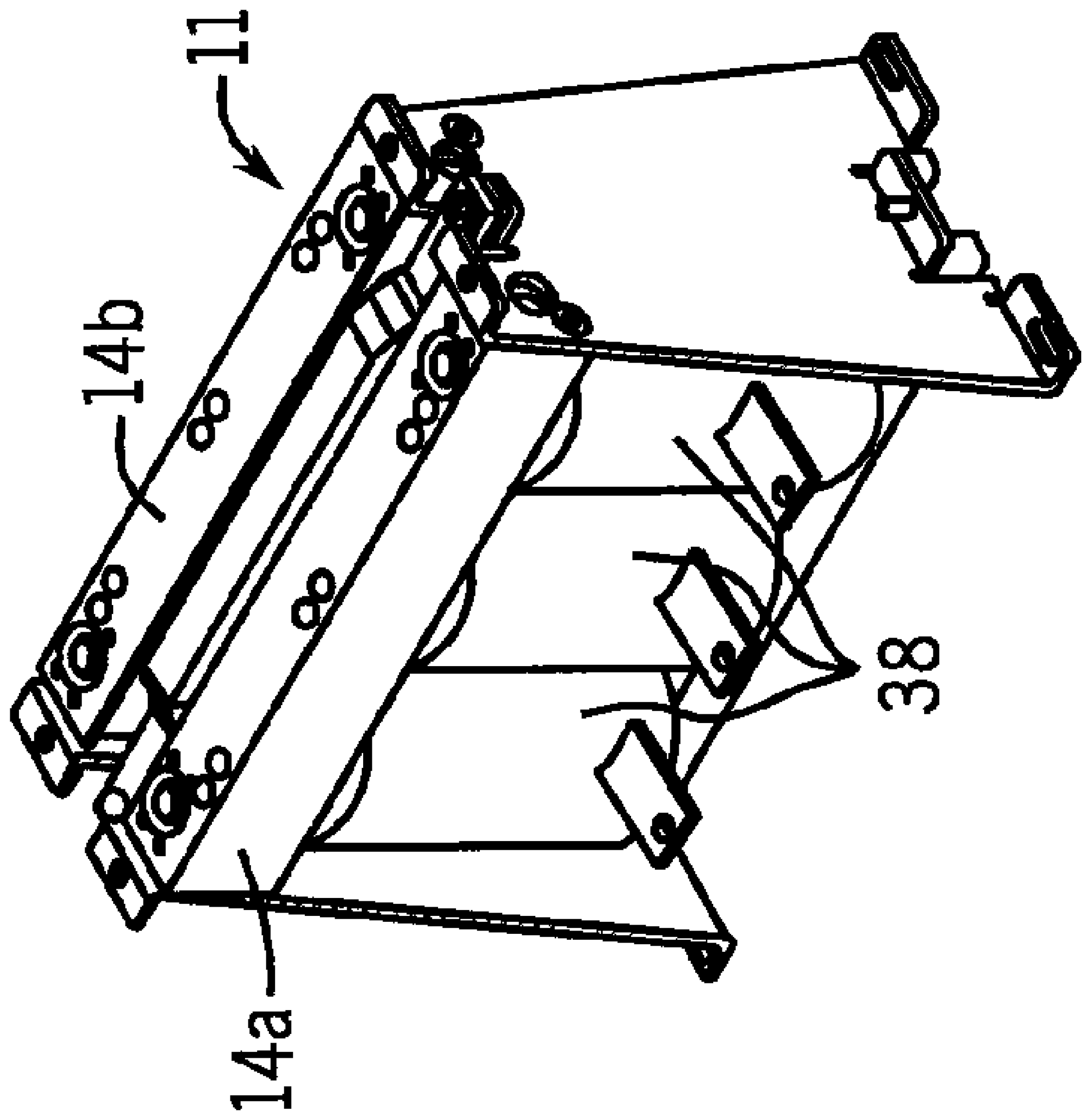

FIG. 13a

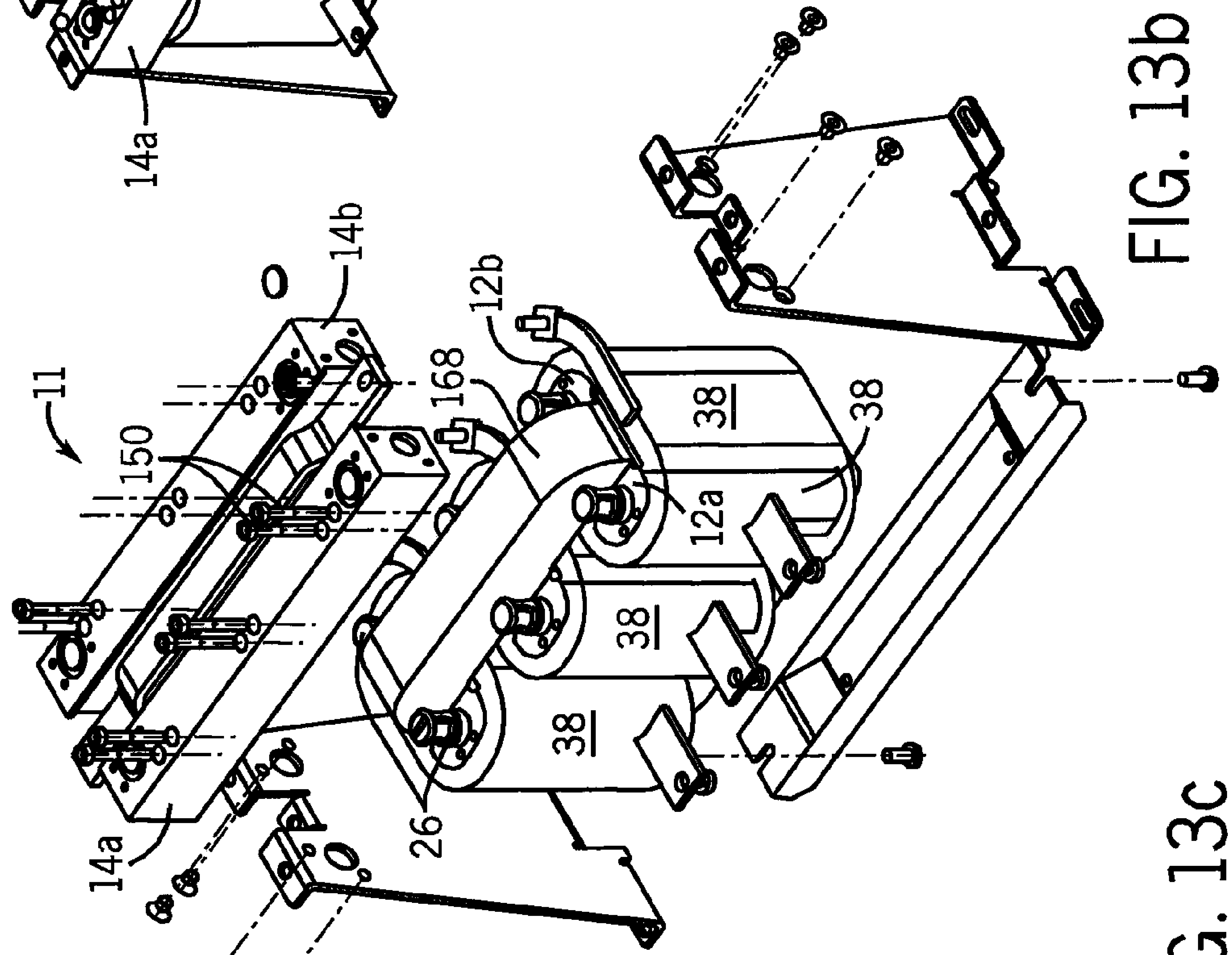

FIG. 13b

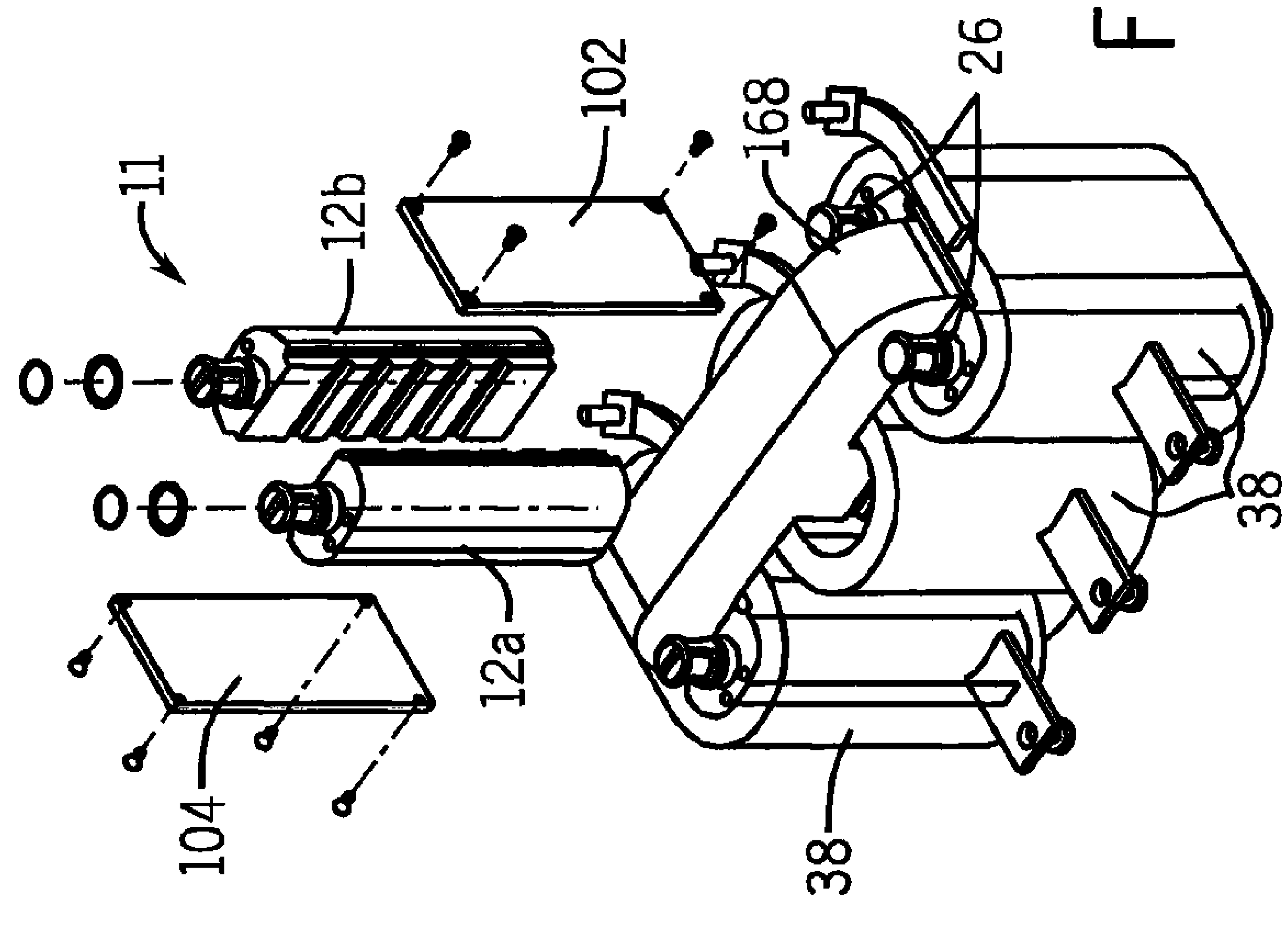

FIG. 13c

MODULAR LIQUID COOLING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 11/854,818, filed Sep. 13, 2007 now U.S. Pat. No. 8,081,462, and entitled “Modular Liquid Cooling System,” which is hereby incorporated by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

TECHNICAL FIELD

The field of the invention is liquid cooling systems and methods for cooling electrical components forming electrical control equipment.

BACKGROUND

Electronics and electrical components generate heat when they operate. In at least some applications heat generated by electrical components can cause damage to those components if the heat becomes excessive. Component heating problems are exacerbated when electronic components are operated in extremely hot environments and/or when the components need to be enclosed (e.g., in a sealed compartment) during operation. For instance, in military vehicles that operate in desert conditions, ambient temperatures in excess of 100 degrees are typical and components often have to be enclosed to protect the components from dust, sand and other airborne debris.

To deal with electronics heating problems, the electronics industry has developed various types of electronics cooling systems including, among others, liquid cooling systems. Typical liquid cooling systems include mechanical tubing or pipe configurations that form channels for directing cooling liquid along paths adjacent heat generating components. Heat from components is dissipated into the cooling liquid and is carried away from the components that generate the heat.

While liquid cooling systems have worked well in many applications, unfortunately the costs associated with manufacturing the mechanical liquid channeling configurations in both materials and labor has been excessive for many applications. To this end, see FIGS. 10 and 11 in U.S. Pat. No. 7,129,808 which issued on Oct. 31, 2006 and that is titled “Core Cooling For Electrical Components” which illustrates a complex circuitous copper tubing arrangement for delivering cooling liquid to components to be cooled where the arrangement includes a large number of components and requires a large amount of skilled labor to assemble.

What is needed is a method and apparatus for configuring liquid cooling systems for electronic and other heat generating components that includes components that are simple to manufacture and that are easy and quick to connect so that minimal skill and time is required to configure cooling assemblies. It would be advantageous if such components were able to be used to configure many different cooling assemblies.

SUMMARY OF THE INVENTION

The invention relates to a liquid cooling system for cooling various electrical components or modules using a liquid coolant. The cooling system includes modular components such as split-flow tubes, split flow manifolds, and single flow manifolds, which are connected together using simply constructed connection pieces and O-rings. The modular nature of these components and the connection pieces allows for the easy assembly and disassembly of these components, and allows for various configurations to be easily constructed to cool different types and numbers of electrical components or modules. In at least some embodiments the manifolds are formed using an extrusion process followed by a machining process to form mounting surfaces, threaded bolt receiving apertures and liquid flow ports which operate as inlet or outlet ports. In at least some embodiments, metallic insert plugs are secured within manifold passageways to close those passageways off at distal ends. The cooling system optimizes the coolant flow path and therefore the power flow, and can accommodate high pressure liquid coolants.

The manifold designs contemplated here allow the cooling system to be manufactured separately from the electrical components and then assembled with the electrical components. Further, this modular cooling system lowers the losses due to heat, reduces internal enclosure temperature, can cause conditions that enable smaller electronic and other components to be used to achieve the same operational output, and allows for lower temperature rated components to be used. Other advantages include a reduction in the heat load of internal devices, the use of smaller components such as inductors due to increased allowable flux density, smaller cores and smaller coil wire size. The cooling system can result in smaller systems, which reduces shipping weight, required package structural strength, and material mass. All of these factors translate to decreased cost.

Consistent with the above, at least some inventive embodiments include a kit of components for configuring electronics cooling configurations, the kit comprising a plurality of passageway forming members, each forming member including an extruded member having first and second ends and forming at least one passageway and at least one of an input port and an output port that opens into the passageway, each forming member also including at least one plug insert secured to the second end of the forming member to block the at least one passageway, a plurality of elastomeric seals, a plurality of mechanical fasteners, wherein forming members can be arranged adjacent each other with ports aligned and the fasteners can be used to mechanically fasten the forming members together with seals there between to form various cooling configurations.

In some cases at least a first of the forming members includes first and second passageways. In some cases the first forming member includes an inlet into the first passageway and an outlet that opens into the second passageway and wherein the first and second passageways are completely separate. In some cases the inlet and outlet into the first and second passageways, respectively, open to the same side of the first and second passageways. In some cases the first and second passageways are substantially parallel.

In some cases the first forming member includes first and second plug inserts at the first and second ends for blocking passageways. In some cases at least a second of the forming members includes first and second passageways, a bridge passageway adjacent the second end that links the first and second passageways and an inlet into the first passageway and an outlet into the second passageway where the inlet and outlet are both proximate the first end of the forming member. In some cases the inlet and outlet that open into the first and second passageways formed by the second forming member open in opposite directions. In some cases the first forming member includes at least one connecting recess that opens into the first and second passageways formed by the first forming member wherein, when the first end of the second forming member is received in the connecting recess, the inlet and outlet of the second forming member open into the first and second passageways formed by the first forming member.

In some cases the first forming member includes a plurality of connecting recesses that open into the first and second passageways formed by the first forming member wherein each of the connecting recesses can receive a first end of a second forming member so that the inlet and outlet of the received second forming member opens into the first and second passageways formed by the first forming member. In some cases the first forming member includes first and second oppositely facing surfaces and wherein the inlet and outlet are formed in the first surface and the connecting recess is formed in the second surface.

In some cases at least a subset of the forming members form a single passageway and include both an inlet and an outlet that open into the single passageway. In some cases the passageways are formed along lengths of the forming members and wherein each of the forming members includes at least one of an inlet and an outlet that opens through a side wall portion of the forming member into at least one of the passageways. In some cases at least a subset of the forming members include external surfaces that form O-ring receiving cannels for receiving elastomeric seals when two forming members are secured together.

In some cases at least a subset of the forming members are substantially rectilinear in cross section. In some cases at least one of the forming members includes first and second passageways, a bridge passageway adjacent the second end that links the first and second passageways and an inlet into the first passageway and an outlet into the second passageway where the inlet and outlet are both proximate the first end of the forming member.

In some cases the kit is for use in cooling at least one electrical component, the electrical component including a coil having a plurality of turns disposed over at least one of the passageway forming members.

Other embodiments include a method of configuring a cooling assembly, the method comprising the steps of extruding a first manifold member that forms at least one manifold passageway that is defined at least in part by a first manifold wall member where the first manifold wall member forms a first external surface, extruding a second manifold member that forms at least one passageway that is defined at least in part by a second manifold wall member where the second manifold wall member forms a second external surface, forming a first port in the first manifold wall member that opens into the passageway formed by the first manifold, forming a second port in the second manifold wall member that opens into the passageway formed by the second manifold, providing an elastomeric seal on the first external surface that surrounds the first opening and securing the second manifold member to the first manifold member with the first and second openings aligned and the seal sandwiched between the first and second external surfaces.

Some methods further include the step of forming a circular recess in the first external surface and wherein the step of providing an elastomeric seal includes placing the elastomeric O-ring in the circular recess. In some cases the passageway formed by the first manifold includes first and second ends and wherein the method further includes the step of securing a plug insert into at least the first end of the passageway to close the passageway formed by the first manifold. In some cases the step of extruding a second manifold includes extruding a second manifold that forms first and second manifold passageways and wherein the step of forming a second port includes forming the second port so that the second port only opens into the first passageway formed by the second manifold.

Some methods further include the step of forming a third port in the second manifold where the third port opens into the second passageway formed by the second manifold. In some cases the third port also opens into the first passageway formed by the second manifold.

Still other embodiments include a method of forming a split flow tube comprising the steps of extruding a tube member that includes first and second passageways separated by an internal wall member where the tube member includes first and second ends, plugging the first and second passageways proximate the first end, removing a portion of the internal wall member proximate the second end of the tube member, plugging the second end of the tube member with a plug insert where the plug insert is dimensioned so that a bridge passageway is formed between the insert and an adjacent edge of the internal wall member and forming inlet and outlet ports in the tube proximate the first end where the inlet port opens into the first passageway and the outlet port opens into the second passageway.

In some cases the step of extruding a tube member includes extruding a tube member that has a substantially D-shaped cross section. Some methods further include the step of, prior to forming the inlet and outlet ports, removing a portion of the tube adjacent the first end to form a cylindrical connection head portion through which the first and second passageways pass, the step of forming the inlet and outlet ports including forming the ports in the head portion. Some methods further include the step of forming an annular recess for receiving an O-ring in the head portion on a side of the ports opposite the first end of the tube.

Still other embodiments include a modular cooling system. The system comprises at least a first passageway forming member and a second passageway forming member, each of the first and second passageway forming members having first and second ends and forming at least one passageway and at least one of an input port and an output port that opens into the passageway. The second passageway forming member includes first and second passageways, a bridge passageway adjacent the second end of the second passageway forming member that links the first and second passageways and an inlet into the first passageway and an outlet into the second passageway, where the inlet and outlet are both proximate the first end of the second forming member. The first passageway forming member includes at least one connecting recess that opens into the first and second passageways formed by the first passageway forming member, the first end of the second passageway forming member being receivable in the connecting recess, such that the inlet and outlet of the second passageway forming member open into the at least one passageway formed by the first forming member when the first end of the second passageway forming member is received in the connecting recess.

Yet other embodiments include a modular liquid cooling system. The system comprises an extruded tube member, the tube member forming first and second passageways and an internal wall member, the internal wall member separating the first and second passageways, where the tube member includes first and second ends. An elastomeric seal is included that is proximate to and surrounds the first end. A plug insert is included at the second end of the tube member, where the plug insert is dimensioned so that a bridge passageway is formed between the plug insert and an adjacent edge of the internal wall member. Inlet and outlet ports are included in the tube member proximate the first end such that the first end, including the elastomeric seal and the inlet and outlet ports, is sealably insertable in and removable from a respective port in a passageway forming member, where the inlet port opens into the first passageway and the outlet port opens into the second passageway, and where, when the first end is inserted in the port in the passageway forming member, the elastomeric seal is sandwiched between and in substantial contact with both the first end and the passageway forming member.

Yet other embodiments include a cooling system. The system comprises a first passageway forming member including first and second ends and at least one connecting recess that opens into first and second passageways formed by the first passageway forming member, and a second passageway forming member that includes first and second ends and inlet and outlet ports proximate the first end such that the first end, including an elastomeric seal and the inlet and outlet ports, is sealably insertable in and removable from the at least one connecting recess, where the inlet port opens into the first passageway and the outlet port opens into the second passageway, and where, when the first end is inserted in the at least one connecting recess, the elastomeric seal is sandwiched between and in substantial contact with both the first end and the first passageway forming member.

These and other objects and advantages of the invention will be apparent from the description that follows and from the drawings which illustrate embodiments of the invention, and which are incorporated herein by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of an exemplary cooling system constructed using components that are consistent with at least some aspects of the present invention;

FIG. **2** is similar to FIG. **1**, albeit from a different vantage point;

FIG. **3** is a cross-sectional view taken along the line **3**-**3** in FIG. **8** showing internal passageways of an exemplary bobbin end piece;

FIG. **4***a* is a bottom plan view of the split flow manifold shown in FIG. **1**, FIG. **4***b* is an end plan view of the manifold shown in FIG. **4***a*, FIG. **4***c* is a top plan view of the manifold of FIG. **4***a*, FIG. **4***d* is a cross-sectional view taken along the line **4***d*-**4***d* of FIG. **4***a*, FIG. **4***e* is a cross-sectional view taken along the line **4***e*-**4***e* in FIG. **4***d*, albeit where a passageway closing insert has been installed, and FIG. **4***f* is a cross-sectional view taken along the line **4***f*-**4***f* of FIG. **4***c;*

FIG. **5***a* is a top plan view of one of the single flow manifolds shown in FIG. **1**, FIG. **5***b* is a bottom plan view of the manifold of FIG. **5***a*, FIG. **5***c* is a cross-sectional view taken along the line **5***c*-**5***c* in FIG. **5***b*, **5***d* is an end view of the manifold in FIG. **5***a* and FIG. **5***e* is an enlarged cross-sectional view showing an insert installed to block the passageway formed by the manifold shown in FIG. **5***a;*

FIG. **6***a* is a side plan view of one of the single flow manifolds shown in FIG. **1**, FIG. **6***b* is a top plan view of the manifold in FIG. **6***a*, FIG. **6***c* is an end plan view of the manifold in FIG. **6***a* and FIG. **6***d* is an enlarged partial cross-sectional view with an insert installed in a passageway formed by the manifold of FIG. **6***a* to block the passageway;

FIG. **7***a* is a front plan view of the manifold link shown in FIG. **1**, FIG. **7***b* is a rear plan view of the manifold of FIG. **7***a* and FIG. **7***c* is a cross-sectional view taken along the line **7***c*-**7***c* of FIG. **7***a;*

FIG. **8** is a perspective view showing a plurality of bobbin assemblies and split flow manifolds that are consistent with at least some aspects of the present invention;

FIG. **9** is an enlarged perspective view of one of the connection portions of one of the bobbin end pieces shown in FIG. **8**;

FIG. **10** is a view similar to FIG. **8**, albeit where split flow manifolds have been connected to the bobbin assemblies;

FIG. **11** is similar to FIG. **10**, albeit where two single flow manifolds have been connected to the split flow manifold shown in FIG. **10**;

FIG. **12** is a partially exploded view showing two power modules and two single flow manifolds that are consistent with at least some embodiments of the present invention; and

FIG. **13***a* is a perspective view of an inductor assembly and cooling assembly that is consistent with at least some aspects of the present invention, FIG. **13***b* is an exploded view of the assemblies of FIG. **13***a* and FIG. **13***c* is a partially exploded view of a subset of the components of FIG. **13***a* showing, in particular, an exploded bobbin assembly separated from an associated coil.

DETAILED DESCRIPTION

Referring now to the drawings wherein like reference numeral correspond to similar elements throughout the several views and, more specifically, referring to FIGS. **1**-**12**, the construction of and components of one embodiment of a cooling system **10** that is consistent with at least some aspects of the present invention for cooling one or more electrical components, such as an inductor assembly (not shown in FIGS. **1**-**12**) and IGBT modules **25** is illustrated. Second, exemplary inductor/cooling system **11** consistent with at least some inventive aspects is shown in FIGS. **13***a* through **13***c* and will be described in greater detail below.

In FIGS. **1** and **2**, cooling system **10** includes components for directing flow of a liquid coolant, such as closed end split flow tubes **12***a*, **12***b*, **12***c*, etc., that together with separator plates **102** and **104**, form inductor bobbins **100**, split flow manifolds **14***a*, **14***b*, **14***c* and **14***d*, and single flow manifolds **16***a*, **16***b*, **16***c* and **16***d* which operate as source or return manifolds. Here, the manifolds and tubes are collectively referred to as passageway forming members. As further explained below, the tubes and manifolds (i.e., passage forming members) are modular in nature and can be connected together in various ways to achieve both serial and parallel flow of liquid coolant to provide cooling to electrical components.

In at least some embodiments, manifolds **14***a*-**14***d* and **16***a*-**16***d*, are constructed as extruded pieces with additional ports and other features (e.g., mounting surfaces, fastening apertures, etc.) being machined therein. Similarly, split flow tubes **12***a*, **12***b*, **12***c*, etc., that form bobbin end pieces for inductor windings (not shown in FIGS. **1**-**12**) are formed via an extrusion process followed by machining to form functional features including a connection head portion **26** that has inlet or input and outlet or output ports **32** and **34**, respectively. Cooling system **10** also includes plugs **18** (see FIGS. **3**, **4***e*, **5***e*, etc.) and O-rings **22** (see FIG. **3**) to facilitate hermetically sealed connectivity, and bolts for fastening system components together.

Referring to FIGS. **1**, **8** and **9**, an inductor bobbin **100** around which an inductor coil **38** (see FIGS. **13***a* and **13***b*) may be wound in at least some inventive embodiments includes two split flow tubes **12***a* and **12***b* and two separator plates **102** and **104** that are secured via screws to the bobbin end pieces to, as the label implies, space apart the two bobbins to form a core receiving space **106**. End pieces **12***a* and **12***b* are similarly constructed and operate in a similar fashion and therefore, in the interest of simplifying this explanation, only piece **12***a* will be described here in detail.

Referring to FIGS. **13***c* and **3**, end piece **12***a* has a generally D-shaped cross-section along most of its length and forms first and second parallel passageways **108** and **110** along its length dimension and a connection head portion **26** at a top or first end. Piece or tube **12***a* is formed by first extruding a two passageway member having a uniform D-shaped cross-section and then machining off the portion of the extruded member at the head portion end to form head portion **26**. Head portion **26** is generally cylindrically shaped and forms an O-ring recess around a neck portion for receiving an elastomeric O-ring **22**. Input/inlet and output/outlet ports **32** and **34**, respectively, are machined into opposite sides of connection head portion **26** where port **32** opens into first passageway **108** and port **34** opens into second passageway **110**.

At the end of tube **12***a* opposite head portion **26** the wall **112** that separates passageways **108** and **110** is machined off and a metallic plug insert **18** is laser welded in the passageway to close off that end of the tube. Here, the insert **18** stops short of the passageway separating wall so that a bridging passageway **114** is formed between passageways **108** and **110**.

At the head portion end of tube **12***a* wall **112** is machined off and an elastomeric gasket **24** is frictionally received within the resulting passageway end to close off that end. Once installed a surface of a passageway formed by a manifold is pressed against the top surface of gasket **24** to hold the gasket **24** in place.

Thus, the inflow portion and the outflow portion of split flow tube **12***a* together form a continuous U-shaped tube passageway through which liquid coolant may flow. The connection head portion **26** of the split flow tube **12** is configured to be insertable in and removable from a respective connecting portion formed as a recess **44** of a respective split flow manifold, with O-ring **22** and gasket **24** providing a fluid tight connection between the connected components.

Referring again to FIGS. **1** and **2**, each of split flow manifolds **14***a*-**14***d* is similarly constructed and operates in a similar fashion and therefore only manifold **14***a* will be described here in detail in the interest of simplifying this explanation. Referring to FIGS. **4***a*-**4***f*, manifold **14***a* is generally rectangular in cross-section and forms first and second parallel passageways **46** and **48** along its length. As in the case of split flow tube **12***a* described above, manifold **14***a* is formed via an extrusion process to form the rectilinear cross-section and parallel passageways **46**, **48**. Thereafter, inlet and outlet ports and threaded mounting apertures are formed via a machining process. In the illustrated embodiment an inlet port **52** is formed in a top surface or manifold wall member of manifold **14***a* where port **52** opens into passageway **46** and an outlet port **56** is formed in the top surface that opens into passageway **48**. Circular O-ring receiving recesses **58** are formed around each of the inlet and outlet ports **52** and **56** on the top surface. In addition, three outlet/inlet ports or connecting recesses collectively identified by numeral **44** are formed in a bottom surface of manifold **14***a* opposite the top surface where each of the outlet/inlet ports **44** opens into both passageways **46** and **48** (see also FIG. **8**). Each port **44** includes a flat end surface **57** (see FIG. **4***d*).

Outlet/inlet ports **44** are formed to receive connection head portions **26** (see again FIGS. **3** and **9**) of the split flow tubes/bobbin end pieces. To this end, ports **44** are formed so that when a head portion **26** is received therein, a top surface of gasket **24** contacts end surface **57** (see FIG. **9***d*) of the receiving port **44** to seal portion **26** to the end surface **57** and so that the O-ring **22** (see FIG. **2**) is sandwiched between the head portion **26** and a facing surface of the port **44**. When properly positioned, port **32** opens into manifold passageway **46** and port **34** opens into manifold passageway **48** so that a continuous and sealed flow path is formed from passageway **46** in manifold **14***a* through port **32** into first tube passageway **108**, through tube bridging passageway **114** to second tube passageway **110**, through tube port **34** into manifold passageway **48** to manifold outlet port **56**.

Referring to FIG. **4***e*, metallic plug inserts **18** are provided at opposite ends of the passageways **46** and **48** to close off each of these passageways. Here, each insert **18** is dimensioned so that an internal surface thereof abuts an adjacent end of a dividing wall member **59** that separates the passageways **46** and **48**. Inserts **18** are laser welded in place.

Bolts or other mechanical fasteners can be used to secure manifold **14** to bobbin end pieces **12***a*, **12***b*, etc. Exemplary bolts **150** are shown in the FIG. **13***b* configuration.

Referring now to FIGS. **5***a* through **5***e*, exemplary single flow manifold **16***c* has a generally square cross-section and forms a single passageway **63** along its length dimension. Manifold **16***c* can be formed by an extrusion process that forms the square cross-section and single passageway **63**. After extrusion, outlet/inlet ports and fastening apertures are machined into manifold **16***c*. To this end, as seen in FIGS. **5***b* and **5***c*, in the illustrated embodiment, four outlets collectively identified by numeral **64** are formed in one of the manifold **16***c* wall members that open into passageway **63** and apertures (see FIGS. **5***a* and **5***b*) and threaded apertures (see FIG. **5***d*) are formed in manifold **16***c* for connecting cooling system components together. Referring to FIG. **5***e*, a metallic plug insert **18** is laser welded into one end of passageway while an opposite inlet end **62** remains open. Manifold **16***d* is similar to manifold **16***c*.

Referring to FIG. **11**, manifold **16***c* operates as a source manifold and manifold **16***d* operates as a return manifold. To this end, liquid coolant flows into inlet end port **62** (see also FIG. **10***c*) of single flow source manifold **16***c* to be distributed to inlet ports **52** (see FIG. **9***c*) of the plurality of split flow manifolds **14***a*-**14***d*, flows through these split flow manifolds **14***a*-**14***d* and split flow tubes **12***a*, **12***b*, **12***c*, etc., as described above, then flows out of outlet ports **56** (see again FIG. **4***c*) of the split flow manifolds **14***a*-**14***d* to bottom ports **64** of single flow return manifold **16***d* and out of the end port **62** thereof (see also the flow path arrow **154** in FIGS. **1** and **2**).

Referring to FIGS. **1**, **2** and **6***a*-**6***d*, manifold **16***a* is generally rectilinear in cross-section and forms a single passageway **80** along its entire length. Manifold **16***a* is formed via an extrusion process that forms the rectilinear cross-section and passageway **80**. After extrusion, ports and mounting apertures as well as recessed mounting surfaces are machines into manifold **16***a*. In this regard, as seen in FIGS. **6***a* and **6***b*, recessed module mounting surfaces **140** and **142** are formed in manifold **16***a* that are dimensioned to, as the label implies, receive portions of modules **25** for mounting purposes. First and second outlet/inlet ports **84** are formed in surfaces **140** and **142** that open into passageway **80** (see FIG. **11***a*). Ports **84** are dimensioned and configured to receive connection head structure **75** of modules **25** (see FIG. **12**). A plug insert **18** is laser welded into a closed end of passageway **80** (see FIG. **11***d*). Modules **25** can be screwed to or otherwise mechanically fastened to manifolds **16***a* and **16***b* so that structure **75** is received in ports **84**. Manifold **16***b* is similar to manifold **16***a*.

As shown in FIGS. **1** and **2**, a connector or manifold link **27** can connect single flow manifold **16***b* to single flow manifold **16***c* at their open end ports. Referring also to FIGS. **7***a* through **7***c*, exemplary link **27** includes an extruded elongated member that is substantially rectilinear in cross-section and that forms a single passageway **90** (see FIG. **12***c*) that extends along the length thereof. After extrusion, mounting holes, ports and O-ring receiving channels are machined into link **27**. The ports include an inlet port **92** and an outlet port **94** where O-ring recesses **96** and **98** are formed in an external link surface surrounding ports **92** and **94**, respectively. Plug inserts (one shown as **18**) may be laser welded at opposite ends of link **27** to close off ends of passageway **90**.

Referring to FIG. **12**, other electrical components in the form of one or more IGBT modules **25** through which liquid coolant can flow are shown. Each IGBT module **25** includes internal passageways (not shown) with an input port **72** and an output port **74**, both formed in connecting head structure **75**. The connecting head structure **75** includes a cylindrical extension member and an O-ring mounted thereto for sealing purposes.

Referring now to FIGS. **8**,**10**,**11**,**12** and **1** and **2**, to assemble the cooling system **10** shown in FIGS. **1** and **2** after bobbin assemblies **100** (see FIG. **1**) have been configured as described above, manifolds **14***a*-**14***d* are mounted to the bobbin assemblies (see FIGS. **8** and **10** specifically). Next, single flow manifolds **16***c* and **16***d* are mounted to manifolds **14***a*-**14***d* (see FIG. **11**) via bolts and so that the ports **64** (see FIG. **5***c*) of manifold **16***c* open into the inlet ports **52** (see FIG. **4***c*) of manifolds **14***a*-**14***d* and the ports **64** of manifold **16***d* open into the output ports **56** (see FIG. **4***c*) of manifolds **14***a*-**14***d*.

Continuing, referring to FIG. **12**, modules **25** are mounted to manifolds **16***a* and **16***b* with structures **75** received in inlet/outlet ports **84** (see FIG. **6***b*) and then manifolds **16***a* and **16***b* are mounted adjacent/above manifolds **16***c* and **16***d*. Referring to FIGS. **1** and **2**, link **27** is mounted to adjacent open ends of manifolds **16***b* and **16***c* thereby connecting passageways **80** and **63** via link passageway **90** (see also FIGS. **5***c*, **6***d* and **7***c*).

Referring to FIGS. **1** and **2**, in operation, liquid coolant is directed along the path indicated by arrow **154** into input port **85** of single flow manifold **16***a*, flows through manifold **16***a* and out multiple output ports **84** (see FIG. **11***b*), travels through IGBT modules **25** to cool those modules, exits the IGBT modules **25** to single flow manifold **16***b* via ports **84** (see FIG. **6***b*), then travels through manifold **16***b* out an output port to link **27**, to an input port **62** of single flow manifold **16***c*. As shown in FIG. **2**, coolant from single flow manifold **16***c* feeds first passageways **46** (see FIG. **4***d*) of split flow manifolds **14***a*-**14***d*, then flows into and out of split flow tubes **12***a*, **12***b*, etc., back to second passageways **48** of split flow manifolds **14***a*-**14***d* (see FIG. **4***e*), and then to the single flow manifold **16***d*, from which the liquid coolant exits from a single port **62**.

Referring now to FIGS. **13***a*-**13***c*, the second exemplary inductor/cooling configuration **11** includes three inductor coils **38** and a core assembly **168** as well as a cooling assembly. The cooling assembly includes a separate bobbin assembly **100** (e.g., end pieces **12***a*, **12***b* and separator plates **102** and **104**) for each coil **38**, first and second split flow manifolds **14***a*, **14***b* and seals, screws, etc. Once assembled, two bobbin end piece connection head portions **26** extend upward from each coil **38**. Split flow manifolds **14***a*, **14***b* mount to the bobbin end pieces (see FIG. **12***b*) via bolts **150** for delivering cooling liquid to the split flow tubes (e.g., the bobbin end pieces **12***a*, **12***b*, etc.). Although not labeled, bracket components are shown for securing various system components together.

Thus, it should be appreciated that a simple and relatively inexpensive kit of parts has been described that can be used to configure many different cooling system configurations to cool various electronics and heat generating component configurations. The kit includes parts that seal together using simple mechanical fasteners and therefore cooling configurations can be constructed without requiring soldering and welding skills.

Cooling kits such as the exemplary one described above can be simply assembled and/or scaled to provide a system to for cooling many other types and/or numbers of electrical components. For example, bobbins **100** and split flow manifolds **14***a* and **14***b* have been shown in two different configurations **10** and **11** above. The kit of components described above may be configured in many other assemblies.

This has been a description of a preferred embodiment of the invention. It will be apparent that various modifications can be made without departing from the scope and spirit of the invention, and these are intended to come within the scope of the following claims.

We claim:

1. A modular cooling system comprising:

at least a first passageway forming member and a second passageway forming member, each of the first and second passageway forming members having first and second ends and forming at least one passageway and at least one of an input port and an output port that opens into the passageway;

the second passageway forming member including first and second passageways, a bridge passageway adjacent the second end of the second passageway forming member that links the first and second passageways and an inlet into the first passageway and an outlet into the second passageway, where the inlet and outlet are both proximate the first end of the second forming member; and

the first passageway forming member including at least one connecting recess that opens into the first and second passageways formed by the first passageway forming member, the first end of the second passageway forming member being receivable in the connecting recess, such that the inlet and outlet of the second passageway forming member open into the at least one passageway formed by the first forming member when the first end of the second passageway forming member is received in the connecting recess.

2. The system of claim **1** wherein each of the first and second passageway forming members also includes at least a first plug insert secured to the second end of each passageway forming member to block the at least one passageway at the second end.

3. The system of claim **1** further including a plurality of elastomeric seals and a plurality of mechanical fasteners, the mechanical fasteners to mechanically fasten the first passageway forming member and the second passageway forming member together; and

wherein the first passageway forming member input port, at least one of the plurality of elastomeric seals, and the second passageway forming member output port are arranged in substantial structural alignment with each other such that the at least one of the plurality of elastomeric seals is positioned between and in substantial contact with both the first passageway forming member and the second passageway forming member to create a sealed flow path between the first passageway forming member input port and the second passageway forming member output port.

4. The system of claim **1** wherein the first passageway forming member includes a plurality of connecting recesses that open into the first and second passageways formed by the first passageway forming member, and wherein each of the connecting recesses can receive a first end of a second passageway forming member so that the inlet and outlet of the received second passageway forming member opens into the first and second passageways formed by the first passageway forming member.

5. The system of claim **1** wherein at least a subset of the first and second passageway forming members form a single passageway and include both an inlet and an outlet that open into the single passageway.

6. The system of claim **1** wherein the passageways are formed along lengths of the first and second passageway forming members, and wherein the first and second passageway forming members include at least one of an inlet and an outlet that opens through a side wall portion of at least one of the first and second passageway forming members into at least one of the passageways.

7. The system of claim **1** wherein at least a subset of the first and second passageway forming members include external surfaces that form O-ring receiving channels for receiving at least one of a plurality of elastomeric seals when the first and second passageway forming members are secured together.

8. The system of claim **1** to cool at least one electrical component, the electrical component including a coil having a plurality of turns disposed over at least one of the first and second passageway forming members.

9. The system of claim **1** wherein the first passageway forming member includes a circular recess in the first external surface and wherein the at least one elastomeric seal is placed in the circular recess.

10. The system of claim **9** wherein the elastomeric seal comprises an elastomeric O-ring.

11. The system of claim **1** wherein the first passageway forming member includes first and second passageways.

12. The system of claim **11** wherein the inlet and outlet of the second passageway forming member open into the first and second passageways formed by the first forming member.

13. The system of claim **12** wherein the first forming member includes an inlet that opens into the first passageway formed by the first passageway forming member and an outlet that opens into the second passageway formed by the first forming member, and wherein the first and second passageways are completely separate.

14. The system of claim **13** wherein the first passageway forming member includes first and second oppositely facing surfaces, and wherein the inlet and outlet are formed in the first surface and the connecting recess is formed in the second surface.

15. The system of claim **1** wherein the first end forms a cylindrical connection head portion through which the first and second passageways pass.

16. A cooling system comprising:

a first passageway forming member including first and second ends and at least one connecting recess that opens into first and second passageways formed by the first passageway forming member; and

a second passageway forming member including first and second ends and inlet and outlet ports proximate the first end such that the first end, including an elastomeric seal and the inlet and outlet ports, is sealably insertable in and removable from the at least one connecting recess, where the inlet port opens into the first passageway and the outlet port opens into the second passageway, and where, when the first end is inserted in the at least one connecting recess, the elastomeric seal is sandwiched between and in substantial contact with both the first end and the first passageway forming member.

17. The system of claim **16** wherein at least one of the first and second passageway forming members are substantially rectilinear in cross section.

18. The system of claim **16** further including a plurality of mechanical fasteners to mechanically fasten the first forming member and the second forming member together.

19. The system of claim **16** wherein the second passageway forming member includes first and second passageways, and each of the first and second passageway forming members also includes at least a first plug insert secured to the second end of each passageway forming member to block the first and second passageways at the second end.

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